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SPACE FLIGHT HAZARDS CATALOG

OCTOBER 6, 1975

M. L. RAINES
DIRECTOR, SAFETY, RELIABILITY
AND QUALITY ASSURANCE

PREPARED BY: NS/SAFETY DIVISION

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1.0 PREFACE

This document is a compilation of hazard descriptions which have been identified in the manned space flight programs, including Mercury, Gemini, Apollo, Skylab, and the Apollo/Soyuz Test Project. This summary is intended to provide an element of experience retention in the identification of hazards. In order to keep the catalog as simple and concise as possible, each listing is limited to material descriptive of the hazard or necessary to understand its nature. No attempts have been made to discuss possible methods of avoidance, to assess the degree of risk involved in available alternatives, or to identify the specific program involved. Such information will be made available upon request to the JSC Safety Division, mail code NS. Recipients are encouraged to forward to the same address suggested additions to the catalog.

This issue of this catalog constitutes a complete revision to previously published editions, including a revision of format, and an increase of approximately 30 percent in the number of enteries. Therefore, no attempt has been made to indicate specific areas that have been altered or added.

Addressees are requested to forward this catalog to those persons having an interest in the design, fabrication, checkout or operation of spaceflight equipment.

2.0 INTRODUCTION

2.1 GENERAL

Man's first landing on the moon on July 20, 1969, marked the culmination of 10 years of intensive effort in learning how to design, build, and operate space vehicles. During this period, most of the significant hazards associated with space flight were identified and circumvented successfully by the engineers directly involved in the on-going programs. This document is intended to increase awareness of the hazards that were identified during those early years of manned space flight and during the most recent Skylab and Apollo Soyuz programs.

In the interest of brevity, each listing is limited to descriptive material necessary in understanding the nature of the hazard.

2.2 PURPOSE

This document provides current and future space program designers, managers, and analysts with a single reference listing of the most significant hazards identified on previous manned space flight programs. This summary is of special value to system safety engineers in developing safety checklists and otherwise tailoring safety tasks to specific systems and subsystems to provide assurance that "lessons-learned" from previous programs are retained.

3.0 HAZARDS CATALOG ORGANIZATION

In this catalog, hazards are presented in nine major categories related to major spacecraft subsystems or to overall spacecraft operations (refer to Table I). These categories are further divided into 18 subcategories which relate to general problem areas such as toxicity, corrosion, vibration, etc. (refer to Table I). To minimize duplication, hazards are listed in the most appropriate category and subcategory. For example hazards pertaining in general to fluids and gases are listed in the "fluid" major category. They are then divided into the most appropriate subcategory for easy reference.

TABLE I. - HAZARDS CATALOG CATEGORIES

MAJOR CATEGORIES	SUBCATEGORIES
Environmental	Configuration
Structural	Fabrication
Mechanical	Contamination
Electrical	Toxicity (including irritants)
Fluid	Flammability
Propulsion	Corrosion
Explosive	Vibration
Aerodynamic	Human error
Operational	Improper procedures
	Defective or unsuitable equipment
	Verification of equipment
	Handling of equipment
	Protection from environment
	Operational status information
	Pressure control
	Leakage
	Overloads
	Transients

4.0 ENVIRONMENTAL HAZARDS

4.1 CONFIGURATION

4.1.1 Failure of cabin pressure relief valve to relieve during launch and reentry phases of flight.

4.1.2 Inadequate provisions to prevent cabin ventilating fans from jamming caused by debris floating in zerogravity conditions.

4.1.3 Inadvertent switch actuation because of inadequate marking, inadequate guarding, improper spacing, or positioning on panels.

The problem is accentuated during suited operations by the lack of a sense of feel with pressurized suits and gloves.

4.1.4 Inadequate provisions to keep overboard dump lines functional because of clogging or freeze-up.

4.1.5 Lack of moisture protection for sensitive equipment which is mounted near plumbing lines, cold plates, etc.

4.1.6 Sharp points or edges that could injure crewmen or tear pressure suits in the crew bay or during extravehicular activity.

4.1.7 Venting of the crew bay to space through the same opening used to vent liquids or harmful gases.

The opening may freeze and prevent pressure relief of the crew bay.

4.1.8 Lack of screens to prevent entry of tools, hardware, or debris into sections of the spacecraft where interference with the operation of spacecraft equipment could result.

4.1.9 No isolation capability for multiple pressure suits on a common pressure source to ensure retention of a survivable environment in the remaining suits if one suit ruptures.

4.1.10 Lack of protection against actuation of equipment by involuntary movements of a sleeping crewman.

This problem is accentuated in zerogravity by permitting arms and legs to float away from couches or seats. This problem is most critical in solo operations.

4.1.11 Cabin pressure relief valves that are sensitive to and unprotected from debris of the type that could reach them under zerogravity conditions.

4.1.12 No provisions for an audible alarm warning to indicate low or rapidly decreasing spacecraft cabin pressure.

4.1.13 No provisions to prevent water penetration in the crew cabin during water landing.

4.1.14 Inadequate provisions to prevent the introduction of undesirable gases into the breathing gas supply systems.

4.1.15 Switches and controls not protected from impact of heavy or rigid equipment that must be donned, worn, or moved about in the crew bay.

4.1.16 Deployed equipment chilled below the cabin dew point not protected against condensation when reintroduced to the cabin environment.

4.1.17 Deployed equipment heated above touch temperature limits not adequately protected from the crew and temperature sensitive equipment when reintroduced to the cabin environment.

4.1.18 Inability to regulate cabin pressure remotely for each compartment of the spacecraft.

4.1.19 Failure to provide a warning indication when the spacecraft habitable environment relief valve(s) and other venting devices are not fully seated.

4.1.20 Lack of protection of the crew and equipment from the release of shattered material fragments.

4.1.21 Location of exhaust ports in proximity to relief valves may allow gas ingestion on reentry, hazardous gases may be drawn into the crew bay along with the outside air.

4.1.22 Expansion of closed cell foam materials due to pressure change when such materials are used as cushions, equipment stowage pads or spacers may produce undesired configuration changes.

4.2 CONTAMINATION

4.2.1 Spacecraft windows and optical surfaces obscured by outgassing materials, overboard dumps, or engine exhaust.

4.2.2 The use of mercury inside the spacecraft habitable environment without suitable protection.

4.2.3 Inadequate means of decontaminating equipment and personnel exposed to radioactive materials.

4.2.4 Improper sealing of pathogenic biological payloads.

4.2.5 Lack of adequate protective covers for equipment containing lenses.

4.2.6 Lack of caution and warning sensors for pathogenic biological equipment.

4.2.7 Inadequate provisions for preventing release of radioactive materials in the event of an accident.

4.2.8 Lack of radiation dosimeters for each crewman when payloads or operational environments involve potentially high radiation sources.

4.2.9 The use of radioactive materials for illuminating purposes without positive mechanical protection against abrasion, flaking, or direct crew contact.

4.2.10 The use of nonlife supporting gas to purge habitable modules without provisions to assure adequate oxygen levels and gas mixing prior to crew entry.

4.2.11 Use of drinking water not properly purified.

4.2.12 Release of biocide such as potassium iodide/iodine solution into habitable areas of a spacecraft.

4.2.13 The use of water generation/storage equipment susceptible to metallic ion contamination.

4.2.14 Residuals from cleaning operations may react with lithium chloride when circulated through carbon dioxide absorbent canisters producing toxic substances.

4.2.15 Silicone rubber RTV (room temperature vulcanizing) compounds which release acetic acid during curing cause corrosion to incompatible materials, such as lead, brass, and solder

4.2.16 Halogen acids released by hydrolysis of halogens (blowing or curing agents) in certain urethane foam thermal insulations or polyester paints may corrode metals to which they are applied.

4.2.17 Anaerobic thread locking compounds (such as "loctite") used on screws which are removed or turned after the compounds have hardened may generate particulate contamination. This is due to the brittle, crumbly nature of the hardened compounds.

4.2.18 Inadequate strength of packaging materials and package seals for food packages, operational supplies, etc., may allow bursting or leakage of contents as a result of cabin pressure changes.

4.3 TOXICITY

4.3.1 Entry of toxic fumes into spacecraft cabin during reentry.

4.3.2 The use of shatterable or shreddable materials in the crew bay whose particles would be injurious to the crew.

Includes use of paints or coatings that can flake.

4.3.3 The use of paint or coatings which contain carbon black in the crew bay.

Carbon black outgasses carbon monoxide which is not removed by present environmental control systems.

4.3.4 The use of cadmium in the crew bay.

Cadmium outgasses toxic fumes at low pressure or at elevated temperatures.

4.3.5 Ethylene glycol, Coolanol, or other coolant fluid vapors in the cabin or suit atmosphere.

In concentrations greater than 25 to 70 parts per million, these vapors produce intolerable throat, eye, and nose irritation requiring emergency action, e.g., use of oxygen masks and mission abort.

4.3.6 Inadequate means of controlling the presence of an unacceptable toxic environment in the spacecraft.

4.3.7 Lack of emergency provisions to purge contaminants from spacecraft volumes or to provide emergency breathing capability.

4.3.8 Contamination of spacecraft breathing gas systems with mercury.

> The use of mercury in testing and calibrating valves, instruments, etc. can result in dangerous levels of toxic mercury vapor in spacecraft breathing gas systems.

4.3.9 Contamination of packaged food or drinking water with mercury.

4.3.10 Undetected buildup of carbon dioxide in cabin or suit circuit.

4.3.11 The use of beryllium, beryllium oxides, or alloys containing more than 4 percent of beryllium inside the spacecraft habitable environment without suitable protection.

4.4 FLAMMABILITY

4.4.1 Inadequate control of flammable materials in oxygen rich environments.

4.4.2 Sparks generated by removal of containers, e.g., removal of lithium hydroxide canisters from their storage compartments in the crew bay.

4.4.3 Static charges generated from suits and couches in the crew bay.

4.4.4 Use of dichloroethane in spacecraft which utilize lithium hydroxide for carbon dioxide control.

> Dichloroethane mixed with lithium hydroxide can generate acetylene which is highly flammable in the spacecraft oxygen atmosphere.

4.4.5 Improper provisions for the stowage of flammable, explosive or gas generating materials.

4.4.6 Components capable of causing ignition used in areas with flammable vapors, liquids, or other combustible materials.

4.4.7 Lack of adequate fire detection and control devices where required.

4.4.8 Inability of enclosure containing flammable materials to contain combustion to prevent propagation.

4.5 PROTECTION FROM ENVIRONMENT

4.5.1 Failure to provide ear protective devices in high noise environments.

4.5.2 Exposure of crew members to high intensity light.

4.5.3 Use of single pane spacecraft windows without positive assurance of pressure retention capability in case of failure.

4.5.4 Lack of ultraviolet and infrared shielding on spacecraft viewing and photographic windows.

4.5.5 Lack of proper crew protection for handling extremely hot or extremely cold equipment.

Hardware which has been exposed to space environment for long periods of time may be extremely hot or cold, depending upon whether the hardware was exposed to direct sunlight or in the shade of the spacecraft or other objects.

5.0 STRUCTURAL HAZARDS

5.1 CONFIGURATION

5.1.1 Inadequate or incorrect stress analysis.

5.1.2 Improper venting of space vehicle interstage compartments and shrouds.

5.1.3 Structural crevices where debris can become lodged in a way that produces local stress concentrations in tank skins.

5.1.4 Inadequate allowance for distortions and stresses resulting from thermal expansion or contraction.

5.1.5 Vulnerability of crew bay floor to unrecognized damage under one gravity conditions because of weight of people and equipment or impact of dropped tools.

5.1.6 Damage due to elastic recoil of vehicle structure under strain at time of holddown release.

5.1.7 Inadequate venting of enclosures to protect against buildup of internal pressure from evaporation of trapped moisture or outgassing during aerodynamic heating.

5.1.8 Damage due to elastic recoil resulting from abrupt engine shutdown.

5.1.9 Puncture of tanks by projections on adjacent hardware, resulting from inadequate allowance for structural distortions.

5.1.10 Inability of equipment and component containers within the habitable areas of the spacecraft to withstand decompression and recompression.

5.1.11 Vacuum vent plumbing inadequately protected from mechanical damage.

5.1.12 Inadequate protection from pyrotechnic shock effects.

5.1.13 Insecurely mounted equipment without sufficient margins for operational loads, including normal or contingency landings.

5.1.14 Excessive dynamic loads in flight due to longitudinal oscillations (POGO) resulting from engine thrust variations.

5.2 FABRICATION

5.2.1 Unsatisfactory bonding of skins on honeycomb structural elements.

5.2.2 Hydrogen embrittlement of 4130 or 4340 steel heat-treated above 180 thousand pounds per square inch and preloaded in tension.

5.3 FLAMMABILITY

5.3.1 Lack of fire extinguishing agent access to isolated but unsealed containers, panels, or racks where flammability hazards exist.

5.4 CORROSION

5.4.1 Galvanic corrosion of structure under lead-sheathed shaped charges.

5.4.2 Use of metal couples that create unacceptable galvanic corrosion.

5.4.3 Materials or components adjacent to fluid lines or containers which contain incompatible fluids.

5.4.4 Stress corrosion resulting from:

a. Overtorque or overload beyond stress corrosion limits.

b. Exposure to environments not anticipated in design.

6.0 MECHANICAL HAZARDS

6.1 CONFIGURATION

6.1.1 Premature initiation of sequences by false signal of stage or module separation caused by:

a. Separation sensors with inadequate travel triggered by structural deflections.

b. Faulty system design allowing signal to be generated by malfunction of a single separation sensor.

6.1.2 Lack of retention of the ends of springs to prevent jumping, jarring, or jamming which alters the spring force characteristics.

6.1.3 Gyros and gyro mounting brackets that are not positively keyed to prevent interchanging gyros or installation of a gyro in an incorrect orientation.

This same hazard exists in the case of accelerometers used in guidance systems.

6.1.4 Lack of redundant means of accomplishing critical operation sequences, e.g., separation of reentry module from other modules or equipment that would prevent a safe reentry and landing.

6.1.5 Lack of protection of nozzles and vents used in manned spacecraft systems from entrance of rain, debris, or other contaminants prior to launch.

6.1.6 Improper shielding of rotating elements to prevent damage resulting from exploding fragments.

6.1.7 The use of chains, beaded links, or similar segmented devices which can be broken, resulting in loose pieces floating in the spacecraft.

6.1.8 Lack of tethering of locking pins, knobs, handles, protective caps, plugs, and similar devices which require removal during flight operation.

6.1.9 Cargo handling mechanisms that cannot withstand the propulsive forces resulting from leaking or ruptured fluid cargoes.

6.1.10 Inadequate seal replacement provisions for airlocks and similar mechanical devices that penetrate the pressure shell of the habitable area of the spacecraft.

6.2 HANDLING OF EQUIPMENT

6.2.1 Lack of positive mechanical locking devices for lifting devices and tiedowns.

6.2.2 Lack of automatic braking or stop features on lifting mechanism cable drums.

7.0 ELECTRICAL HAZARDS

7.1 CONFIGURATION

7.1.1 Redundant paths not adequately separated.

7.1.2 Failure to key electrical connectors to positively prevent interchanging with other accessible connectors.

7.1.3 Metallic particles in electrical equipment generated by screw threads used to attach covers or connectors.

7.1.4 Inadequate means of protecting electrical equipment from effects of particles or parts floating in zerogravity environments.

7.1.5 Failure of the fuel cell separation system to separate completely the hydrogen gas from the potable water.

7.1.6 Inability to checkout pyrotechnic circuits after installation.

7.1.7 Inadequate isolation of pyrotechnic wiring from other spacecraft wiring.

7.1.8 Sharp edges that can contact unprotected electrical wire insulation.

7.1.9 Condensation of contaminated moisture in cooled parts of the electronic equipment.

The crew bay atmosphere will generally be oxygen rich and may contain excessive moisture contaminated with human excretion.

7.1.10 Inability of electronic equipment to maintain undisturbed operation in the presence of transient supply voltage pulses shorter than the response time of power system regulators.

7.1.11 Power system surges outside tolerable limits resulting from equipment turn-on or off.

7.1.12 Electrical wiring in contact with fluid lines.

A short circuit from a hot wire to a grounded fluid line can burn a hole in the line and cause a leak, a gross line rupture, or a fire, depending on the pressure and the type of fluid in the line.

This same hazard exists in the case of fluid tanks.

7.1.13 Lack of protection from damage or corrosion caused by electrolyte leakage or improper venting from batteries.

7.1.14 System design that does not provide a means of verifying in preflight tests that each individual path in a redundant system is operational.

7.1.15 Short or open circuits in biomedical or communications wiring inside pressure suit.

7.1.16 Electrical shock through biomedical or communications wiring.

7.1.17 Electrical energy sources or storage devices (batteries, capacitors) inside the pressure suit.

7.1.18 Solder joint cracking in potted printed circuit board assemblies, including cordwood modules.

7.1.19 Wiring unprotected from damage due to traffic in the crew bay during preflight preparations.

7.1.20 Excessive use of carry-on checkout equipment and need to disconnect vehicle cables for checkout.

7.1.21 Switching of latching relays caused by transients to an unplanned configuration.

7.1.22 Interference of attitude control jets with optical star trackers by:

a. Solar reflection from particles or crystals in jet efflux.

b. Displacement of star image by refraction of light in jet efflux.

c. Corona induced by ionized jet gas impinging on unpressurized electronics of star tracker.

7.1.23 Equipment not designed to survive momentary power interruptions.

7.1.24 Lack of protection for pyrotechnic circuits from transients generated in the space vehicle electrical power system.

7.1.25 Shared firing control circuitry that requires critical systems to be armed during periods when they are not to be used, i.e., while the firing control circuitry is energized to fire other systems.

7.1.26 Failure to remove shorting devices such as springs and clips used in connectors, prior to connector use.

7.1.27 Inadequate marking of mating plugs and wires to indicate correct mating connections or termination points.

7.1.28 Failure to use female connectors at sources of power.

7.1.29 Solid wire (single strand) used in locations where it may be subjected to flexing.

7.1.30 Electrical connector and cable installations with insufficient flexibility, length, and accessibility to permit disconnection and reconnection without damage to wiring or connectors.

7.1.31 Failure to ground or insulate control shafts, knobs, handles, or levers to preclude personnel shock or burn.

7.1.32 Power circuits and signal circuits routed through the same connector causing electromagnetic interference.

7.1.33 Failure to remove electrical power from electrical connectors during engagement/disengagement operations.

7.1.34 Failure to hermetically seal relays, including motor start relays, level sensing devices, switches, cam contacts, commutators, etc., which can produce an electrical arc.

7.1.35 Lack of consideration for potential corona discharge in high voltage or high frequency circuits.

7.1.36 Presence of contaminants or offgassing materials from motor switches, relays, etc.

7.1.37 Failure to passivate solid state devices.

7.1.38 Engine kill circuitry live after holddown release.

7.1.39 Failure to deadface or otherwise protect against shorts in circuits interrupted by guillotine cutters.

7.1.40 Inadequate requirements for redundant relays in critical circuits.

7.1.41 Paralleling relay contacts without protecting against, or eliminating, the possibility that one set of contacts may mate in the new position before the other set has broken from the old position.

7.1.42 Lack of provisions for bleeder resistors to discharge capacitors when equipment is deenergized.

7.1.43 Inadequate means of isolating instrumentation circuitry from operating system circuitry.

7.1.44 Improper isolation of primary and redundant system circuits.

7.1.45 Lack of protection against inadvertent operation of circuit breakers or switches used to control pyrotechnic devices and other circuitry intended for emergency purposes.

7.1.46 Failure of the built-in test equipment to fail safe.

7.1.47 Improper protection of critical circuits from electrical short circuits at connectors.

7.1.48 Internal shorts, overheating, and explosion of batteries.

7.1.49 Inability of batteries to accept multiple recharges without dendrite growth and internal shorts.

7.1.50 Improper thermal isolation between batteries.

7.1.51 Inadequate provisions for battery heat dissipation.

7.1.52 Failure to provide all hermetically sealed batteries with blowout plugs for pressure relief.

7.1.53 Ejection of battery electrolyte from batteries.

7.1.54 Batteries vented into the habitable areas of the spacecraft without adequate atmospheric mixing.

7.1.55 The existence of unintended electrical current paths (Sneak Circuits) which may lead to unplanned system activation with a hidden cause and effect relationship.

7.2 FABRICATION

7.2.1 Ultrasonic cleaning of assembled circuit boards containing transistors.

Internal parts of some transistors are subject to resonant response and fatigue damage at some frequencies used in ultrasonic cleaners.

7.2.2 Soldering of electronic parts to circuit boards in cordwood modules prior to potting between the circuit boards.

Expansion and contraction of potting during cure can damage solder connections.

7.2.3 Stresses on glass diodes from excessive conformal coating.

7.2.4 Use of long screws that penetrate black boxes and damage internal wiring or components.

7.2.5 Inadequate stress relief of soldered connections.

7.2.6 Physical separation and support of uninsulated wires or electronic parts in components not sufficient to ensure against contact under sustained gravity force, vibration, or structural distortion.

7.2.7 Use of swaged eyelets (without soldering or welding) to form an electrical connection between conductors.

7.2.8 Polystyrene parts on circuit boards that are to be coated with polyurethane conformal coatings.

The solvents used in polyurethane conformal coatings may attack and dissolve polystyrene parts.

7.2.9 Application of excessive torque during installation of stud-mounted semiconductors.

Some stud-mounted semiconductors will tolerate only very low installation torques (on the order of 10 inch-ounces) without risk of hermetic seal failure.

7.3 TOXICITY

7.3.1 Polyvinyl chloride used as wire insulation.

7.4 FLAMMABILITY

7.4.1 The use of organic pigments in Teflon wire insulation.

The addition of some organic pigments will make Teflon insulation burn in environments where it would normally be nonflammable.

7.4.2 Inadequate separation of electrical and heat producing components from oxygen systems.

7.4.3 Use of ethylene glycol not inhibited with Benzotriazole in proximity to electrical circuitry containing silver or silver-coated copper.

7.5 CORROSION

7.5.1 Use of sulphur-containing or sulphur-coated materials in close proximity to electrical contacts.

7.5.2 Use of "Locktite" in applications where it can come in contact with magnetic tape.

"Locktite" contains chemicals which damage the iron oxide coating of magnetic tape.

7.5.3 Ingestion of moisture and salts from ambient atmosphere into unsealed components cooled to cryogenic temperatures.

Cooling of components to very low temperatures reduces internal pressure and may cause external air to be drawn in if the component is not hermetically sealed. This breathing action has caused internal contamination and corrosion of electrical equipment in seacoast atmospheres.

7.5.4 Galvanic corrosion products creating a conducting path between normally open switch contacts. Switch contacts not adequately protected from exposure to moisture or moist air.

7.6 VIBRATION

7.6.1 Failure of relays, qualified under launch and boost conditions, to operate under quiescent conditions (e.g., during vehicle coast) due to friction introduced to prevent inadvertent actuation by vibration.

7.6.2 Improper operation of relays during vibration as a result of:

a. Changes in mounting configuration subsequent to qualification tests.

b. Failure to orient sensitive axis to minimize effects of vibration.

c. Failure to orient redundant relays along orthogonal axes.

7.6.3 Use of relays, switches, circuit breakers, or other current interrupting devices which are not qualified for local environmental conditions resulting from strucutral or acoustic shock generated by firing of pyrotechnic devices.

These shocks have been known to cause fracture of the "lead to chip" bonds in transistors. Shock spectrums peaking as high as 8500 g's at 8000 hertz have been noted.

7.7 DEFECTIVE OR UNSUITABLE EQUIPMENT

7.7.1 Improper application or inadequate screening of wet slug tantalum capacitors.

These capacitors have a tendency to discharge prematurely on the first cycle after a long stand period. This characteristic makes them unsuitable for time-delay devices where early timeout would be undesirable.

They are generally very sensitive to polarity reversal. As little as 0.5 coulomb of charge moving in the reverse direction may produce sufficient electroplating of silver onto the anode to degrade performance.

They are prone to progressive electrolytic leakage through seals which is particularly difficult to detect in the incipient stage.

7.7.2 Inadvertent use of counterfeit electronic parts.

7.7.3 Solder balls or weld splash in transistors and relays.

7.7.4 Solder balls or wire whiskers larger than the gap between contacts in normally open momentary-contact switches.

The risk of inadvertent circuit actuation is greatest under zerogravity or vibratory conditions.

The risk of electrical field attraction of large single solder balls or groups of small solder balls to contact points under zerogravity conditions is undetermined.

7.7.5 Insufficient clearance between moving switch contacts and a grounded switch case or switch-operating mechanism.

Elastic overshoot of the contact following switch toggle actuation to open the circuit, or motion of the contact due to vibration or physical shock, can cause momentary short circuiting of the contact to ground. This type of very short duration circuit is difficult to detect during regular spacecraft checkout tests.

7.8 PROTECTION FROM ENVIRONMENT

7.8.1 Corona and arcing due to:

a. Leakage of sealed pressurized components.

b. Inadvertent premature turn-on of equipment.

c. Outgassing more prolonged than anticipated.

7.8.2 Structural failure of spacecraft containers during changes in atmospheric pressure.

7.8.3 Insufficient protection against harmful environmental (salt water) intrusions into electrical systems and power supplies used for postlanding survival and recovery.

7.8.4 Water intrusion into electrical connectors from:

a. Nighttime condensation.

b. Cooling of connectors inside a space vehicle to temperatures below the dewpoint of the interior atmosphere as a result of heat conduction through copper cables extending to a colder environment outside the vehicle.

7.8.5 Improper protection of magnetic latching valves from degradation of latching force by contaminants carried to the pole faces by internal fluid flow.

7.8.6 High resistance coating deposited on electrical contacts from outgassed products of potting compound as a result of elevated temperatures or low pressures.

7.8.7 Decrease of moist environment insulation resistance in electrical components after coating with "Ladicote" for flammability protection.

7.8.8 Arrangement of leads or electronic parts which does not provide relief of strain caused by thermal expansion and contraction.

7.8.9 Resistance changes in metal film resistors caused by electrostatic fields.

Resistance changes up to 6 percent were measured on precision resistors that had been shipped loosely packed in plastic envelopes. Similar resistance changes have been produced by subjecting new resistors to electrostatic fields of 50,000 volts for 30 seconds. Other characteristics of the resistors were unaffected.

Susceptibility of electronic items other than thin film resistors to damage by similar electrostatic fields is undetermined.

7.8.10 Inadequate protection of system from the effects of lightning.

7.9 OPERATIONAL STATUS INFORMATION

7.9.1 Improper rotational speed of guidance system gyros at launch vehicle lift-off or start of spacecraft engine in orbit.

7.9.2 Powering-up systems with latching relays in unknown positions.

7.9.3 Meters or measurement systems supplying critical operating information that can fail without giving an immediate indication that a failure has occurred.

7.9.4 Capability to provide conflicting commands from ground and flight control.

7.10 OVERLOADS

7.10.1 Circuit breakers too large or too slow-acting to protect wiring.

7.10.2 Flammable potting in electrical connectors.

7.10.3 Circuit breakers and switches with flammable cases or operating parts, used in an oxygen-enriched environment.

7.10.4 Contacts and pins in electrical circuits that will fuse or weld within the current/time limits permitted by current limiting or circuit protection devices.

7.10.5 Failure to provide current overload devices for current carrying conductors connected to flight hardware.

7.10.6 Failure of circuit breakers to trip and protect the circuit.

8.0 FLUID HAZARDS

8.1 CONFIGURATION

8.1.1 Freezing of fluid lines inadequately protected from cryogenic fluids or exposure to space.

8.1.2 Reverse installation of fluid line components (such as check valves) whose proper functioning is dependent on direction of flow.

8.1.3 Inability to remove dangerous fluids remotely and rapidly from the vehicle during emergency back-out from a planned operation.

8.1.4 Inadequate provisions for maintaining separation of coolant and electrical components in coolant pumps.

8.1.5 Inadequate protection of pressure-sensitive components against damage from interruption or fluctuations of supply pressure.

8.1.6 Lack of a positive means of assuring that removal of propellant loading lines will not result in backflow of propellant through the fill port.

8.1.7 Systems or operations that cannot survive should a single valve fail to open or close on command.

8.1.8 Location of drain valves at other than low points in fluid systems.

8.1.9 Undesired spacecraft motions resulting from directional venting of onboard gas or liquid.

8.1.10 Loss of system operating fluid through leakage or rupture of a transducer sensing element.

8.1.11 Propellant tanks containing toxic fluids mounted where they are vulnerable to crushing during landing impact.

8.1.12 Soft-seat hand valves upstream of regulators or other contamination sensitive components in fluid systems.

8.1.13 Tank fill ports not accessible from outside the vehicle.

8.1.14 Inadequate provisions for containment and removal of dangerous fluids released in spills, leaks, or sprays occurring at vehicle tank fill ports.

8.1.15 Valve configurations that will release propellants or other damaging fluids into unprepared areas if the electrical power or gas pressure supplied to the valves is interrupted.

Even when the fluid does not escape into unprepared areas, rapid unplanned and uncontrolled dumping can be hazardous since the ullage gas flow rate may be insufficient to prevent tank implosion under atmospheric pressure.

8.1.16 Cryogenic helium-to-fuel heat exchangers that can freeze after engine shutdown occurs leaving fuel trapped in lines between heat exchanger and engine valves.

8.1.17 Manually operated shutoff valves that can be rendered inaccessible by a downstream line rupture.

8.1.18 Eccentrically pivoted butterfly valves separated from pressurized liquid in a tank or line by a gas trap.

When the valve starts to open the gas flows very rapidly through the partially opened valve. The liquid following the gas is accelerated to high velocity and may reach the butterfly long before it is fully opened. If the butterfly is eccentrically pivoted to utilize liquid pressure as an aid to closing it or holding it closed, the impinging high velocity liquid stream can slam it closed and generate water-hammer forces capable of rupturing the piping.

The situation is compounded if the liquid is cryogenic. The rapid reduction in pressure as the gas escapes through the valve and the relatively warm piping in the gas trap cause flash boiling and violent pressure surges in the liquid approaching the valve.

8.1.19 Inadequate protection of lines against damage from mechanical stress and vibration.

8.1.20 Fuel, oxidizer, and propellant lines routed through inhabited areas of the spacecraft.

8.1.21 Relief ports and vent lines located where escaping liquids or gases will be hazardous to personnel or equipment during flight or ground operations.

8.1.22 Shutoff valves installed in series with relief valves without another positive relief device installed in parallel.

8.1.23 Manually operated valves used to bypass pressure regulators or flow control devices.

8.1.24 System connectors not keyed or sized so that it is impossible to connect incompatible gases, fluids, or pressure levels.

8.1.25 Fluid systems with inadequate provisions for shutting off flow to sections of the system which are susceptible to damage or leakage.

8.2 FABRICATION

8.2.1 Failure of brazed joints due to inadequate control of the brazing process.

8.2.2 Failure to make radiographic inspections of pressure vessels after proof tests.

8.2.3 Failure/leakage of "B" nuts due to improper installation.

8.2.4 Use of dye penetrant not liquid oxygen compatible in checking liquid oxygen system valves.

8.2.5 Fluid systems packings should be compatible with the system fluid, even when used as secondary seals. On a Skylab Mission, butyl rubber secondary seals leaked when contacted by nitrogen tetroxide after failure of the metal-to-metal primary seal.

8.3 CONTAMINATION

8.3.1 Orifices, close tolerance valves and contamination-sensitive equipment in fluid systems not adequately protected by filters.

8.3.2 Contamination of spacecraft fluid systems due to inadequate analysis and filtering of fluids immediately prior to loading into spacecraft.

8.3.3 Contamination introduced by momentary reversal of flow (e.g., during chamber pressure surge in a hard start of an engine) with no filter downstream of a device sensitive to contamination.

8.3.4 Lack of recognition that orbital operation of fluid systems imposes increased demands on filters to dispose of debris that in ground operations is normally separated out and held in sumps by gravitational forces.

8.3.5 Inadequate protection of plumbing systems from introduction of contamination when opened for repairs or replacement of components.

Especially critical when the system is opened between a contamination sensitive element and its protective filter.

8.4 TOXICITY

8.4.1 Circulation or storage of toxic fluids within the crew bay.

8.4.2 Bacterial transfer from waste water system to drinking water.

The use of conventional valves to separate waste and potable water systems does not provide adequate insurance against bacterial migration into the drinking water.

8.5 FLAMMABILITY

8.5.1 Exposure of titanium to liquid oxygen or high pressure gaseous oxygen.

8.5.2 Use of solder joints and aluminum tubing in spacecraft oxygen lines.

8.5.3 Use of incompatible materials in liquid or high-pressure gaseous oxygen systems.

8.5.4 Static charge generation in flowing fluid systems.

8.5.5 Presence of ignition sources in the vicinity of propellant system vents.

8.5.6 Inadvertent interchange of identical fuel and oxidizer components without appropriate cleaning.

8.5.7 Explosive reaction of ethylene glycol on contact with nitrogen tetroxide.

8.5.8 Use of hot-wire sensors in hydrogen system.

8.5.9 Nylon seats in ball valves used in high pressure (1800 to 4000 pounds per square inch, gauge) systems.

Such devices have been found to burn in air systems at temperatures developed by compression of air.

8.5.10 Use of flammable fluids as cooling agents.

8.6 CORROSION

8.6.1 Inadequate removal of lubricating fluid used in the drawing process from AISI 316 stainless steel tubing prior to annealing.

During annealing, carbon in the fluid stimulates formation of carbides rich in chromium. This process depletes the chromium in the adjacent metal to the point where intergranular corrosion occurs.

8.6.2 Inadequate removal of pickling acid used to clean tubing after annealing.

The remaining acid attacks the metal and may cause intergranular corrosion during storage of the tubing prior to use.

8.6.3 Corrosion in potable water systems due to chlorine used for water sterilization.

8.6.4 Chemical reaction between cooling fluids and materials used to contain and control the flow of the fluid within the cooling system.

8.6.5 Reduction in strength of titanium resulting from exposure to fluids not verified to be free from adverse stress corrosion effects on titanium.

8.6.6 Titanium exposed to hydraulic fluids at temperatures above 300-degrees Fahrenheit is subject to hydrogen embrittlement

8.7 OPERATIONAL STATUS INFORMATION

8.7.1 Premature depletion of propulsion or attitude control capability not detected by propellant gaging system.

8.7.2 Gas temperature control sensors located in a gas stream carrying condensed liquid droplets at zerogravity.

The flow pattern of the liquid, and hence the evaporative cooling of the sensor may differ significantly from that established in qualification tests or calibrations at one gravity.

8.7.3 Limited life/limited cycle items which require periodic actions such as inspection, recharge, replacement, etc., not identified on tracking and action lists.

8.7.4 Limited life/limited cycle items installed so that time action cannot be accomplished.

8.7.5 Lack of stringent procedures for monitoring limited life/ limited cycle sensitive equipment.

8.8 PRESSURE CONTROL

8.8.1 Pressure relief valves and flow limiting devices not sized to protect against a failed-open regulator.

8.8.2 Pressure drop in ducting downstream of pressure relief valves.

8.8.3 Lack of adequate pressure relief capability in sections of plumbing where cryogenics or hydrogen peroxide can be trapped.

8.8.4 Differential pressure gages without pressure relief provisions to prevent case rupture if high and low pressure connections are inadvertently reversed.

The hazard is greatest when high and low pressure connections are identical in size and type of thread.

8.8.5 Unvented enclosures containing pressure sources or lines that could, through leakage, build up internal pressure in the enclosure.

8.8.6 Bends in exhaust lines downstream of pressure relief vents in high pressure systems.

Bends tend to straighten on venting.

8.8.7 Regulator shutoff valves not qualified for extremes of temperature that can be reached as a consequence of the flow through a failed-open regulator.

8.8.8 Failure to limit pressurant gas flow rate to the maximum required under worst case operating conditions.

8.8.9 Overpressurization of spacecraft systems by ground support equipment not provided with adequate pressure limiting or pressure relief devices.

8.9 LEAKAGE

8.9.1 Inadequate protection against damage from leaks or spills incident to the loading of fluids aboard the vehicle.

8.9.2 Seal and O-ring leakage due to aging or cold flow.

9.0 PROPULSION HAZARDS

9.1 CONFIGURATION

9.1.1 Engine hard start (transient overpressure) due to fuel lead (early injection of fuel relative to oxidizer).

9.1.2 Hypergolic propellants separated by a single weld.

9.1.3 Inadequate protection of propellant valves from damage by heat soak-back from the thrust chambers.

9.1.4 Metal-to-metal rubbing in liquid oxygen pumps.

9.1.5 Combustion instability in rocket engines.

9.2 CONTAMINATION

9.2.1 Clogging of nitrogen tetroxide injector feedlines in attitude control engines caused by nitric acid formed after exposure to atmospheric humidity in preflight ground firings.

9.2.2 Engine explosion due to alcohol flush contamination of hypergolic propellants.

10.0 EXPLOSIVE HAZARDS

10.1 CONFIGURATION

10.1.1 Improper routing, handling, support, and terminating of explosive trains.

10.1.2 Inadequate protection of power supplies from short circuits in fired pyrotechnic devices.

10.1.3 Failure to design and pack parachute reefing line cutters properly to withstand snatch loads imposed by lanyards.

10.1.4 Lack of protective devices on the hot side of individual pyrotechnic devices to ensure firing of other pyrotechnics that are in parallel with one whose hot side shorts to ground after firing.

10.1.5 Insufficient or unsatisfactory redundancy in hot bridge wire pyrotechnic initiators.

Initiators with dual bridge wires have been found to be sensitive to differential to electrical potential between the bridgewires.

10.1.6 Explosive charge in guillotine and tension tie cutters insufficient to sever wire bundle.

Charge requirements are sensitive to bundle position and have been found to be significantly greater when the bundle is pulled against the blade than when it is lying flat on the anvil.

10.1.7 Hygroscopic materials in close proximity to explosives or firing circuits.

10.1.8 Pyrotechnic devices not adequately designed to contain fragments and blast from the explosion.

10.1.9 Damage to one leg of an explosive train by blast from an adjacent redundant let initiated simultaneously but propagating more rapidly.

10.1.10 Ignition through the nozzle of multiple solid propellant rocket systems that may permit the blast from the first rocket ignited to destroy wiring and prevent sufficient electrical firing energy from reaching the remaining rockets.

10.1.11 Deformation of shaped charge liners caused by pressure from off gassing of explosive core materials.

10.1.12 Degradation of lead jacket on explosive trains caused by incompatibility with bonding agents, solvents, or volatiles released during curing.

10.1.13 Desensitization of explosive materials by residuals of solvents used in cleaning operations.

10.1.14 Inability to disarm propellant dispersion (destruct) systems after they have served their purpose, on stages or modules that are to remain in close proximity to the spacecraft or which will be recovered for future use or which may terminate their flight in an inhabited area.

10.1.15 Explosives made more sensitive by chemical reactions between explosives and their containers. (Lead azide + water + silver or copper charge holder = extremely sensitive silver or copper azide.)

10.2 VERIFICATION OF EQUIPMENT

10.2.1 Incomplete identification, manufacturing and storage history, and description of pyrotechnic devices.

10.2.2 Pyrotechnic devices not verified by neutron radiograph inspection and/or X-ray to have proper placement and density of explosive materials and piece parts.

10.2.3 Lack of provisions for conspicuous identification by color code of all pyrotechnic units not intended for flight use.

Units in this category include inert units, rejected flight operational units, and special purpose units such as nonstandard charge units, test and development units, simulators, and charged training units.

10.2.4 Uncontrolled or insufficiently verified test techniques used to demonstrate insensitivity of pyrotechnic devices to initiation by static charges.

By creating a conducting or low resistance path through the explosive mix, these tests can permanently lower the resistance of the device to initiation by subsequent static charges.

10.3 HANDLING OF EQUIPMENT

10.3.1 Failure of packaging, shipping, and storage provisions to protect pyrotechnics from static charges, impact and shock, high and low temperatures, moisture, and contamination.

10.3.2 Pyrotechnic circuit checks with electrical test equipment using, or containing, power sources high enough to fire electroexplosive devices.

10.4 PROTECTION FROM ENVIRONMENT

10.4.1 Failure of pyrotechnic devices due to sublimation of explosives not adequately sealed from space vacuum.

10.4.2 Inadequate protection of solic propellant rocket motors from moisture or other contaminants by seals capable of:

a. Maintaining an internal atmosphere of dry nitrogen at pressures above ambient.

b. Being expelled during normal rocket ignition without damage to the nozzle and without leaving remnants that could alter the normal flow through the nozzle.

c. Providing access for inspection of the grain (if other suitable provisions do not exist).

10.4.3 Inadequate protection of ends of shaped charges and primacord from intrusion of moisture or expulsion of explosive material during vibration and decompression.

11.0 AERODYNAMIC HAZARDS

11.1 CONFIGURATION

11.1.1 Spacecraft aerodynamic shapes having stable attitudes that are unsafe for reentry or parachute deployment.

12.0 OPERATIONAL HAZARDS

12.1 CONFIGURATION

12.1.1 Inadequate procedures to ensure removal of all nonflight equipment prior to flight.

12.1.2 Allowing primary attitude indicators to be switched to display other than basic flight parameters without adequate cautions.

12.1.3 Failure to maintain required pressure in a system because of a common pressure source which is required to supply several demands simultaneously.

12.1.4 Implosion of liquid tanks as a result of inadequate inflow of ullage gas as liquid is drained under atmospheric pressure.

12.1.5 Inadequate provisions for controlling or limiting temperature change in tanks or pressure bottles during pressurization.

12.1.6 Unreported design or manufacturing changes made in production components after qualification tests.

12.1.7 Inadequate locking and securing of electrical connectors and mechanical fasteners.

12.1.8 Lack of protection from air intrusion into purge hydrogen systems.

12.1.9 Inadequate bonding and grounding of equipment, plumbing, and facilities used with liquid hydrogen.

12.1.10 Lack of explosive vapor detection capability in the vicinity of propellant handling operations.

12.1.11 Failure to install positive leak-preventing caps or plugs on fill and test ports prior to flight.

12.1.12 Lack of a single authoritative source of up-to-date information on the actual configuration existing in the stages and interfaces of the vehicle at any time.

12.1.13 High pressure or flammable fluid lines in the vicinity of welding operations.

12.1.14 Lack of distinctive identification on otherwise identical switches on the same panel when incorrect switch selection would create a dangerous situation.

12.1.15 Lack of separate fluid servicing capability for each module of the space vehicle.

12.1.16 Inadequate provisions for verification of crew visibility required on manned spacecraft missions.

12.1.17 Failure to evaluate crew safety impact of changes to baseline configurations (philosophy, hardware, and operations).

12.1.18 Inaccessibility of emergency equipment (e.g., fire extinguisher and oxygen masks) under all identifiable contingencies.

12.1.19 Lack of guards for switches that control critical functions.

12.2 CONTAMINATION

12.2.1 Inadequate protection of breathing oxygen systems from contamination.

12.2.2 Lack of procedures to verify removal of all tools and extraneous equipment prior to closeout for shipment or start of tests.

12.2.3 Circulation of ground fluids (coolants, etc.) through space vehicle systems.

Exposes the flight systems to contamination existing or generated in ground support equipment.

12.2.4 Fogging of spacecraft windows by silicone oil from room-temperature vulcanized compounds not heat cured in vacuum before flight.

12.3 TOXICITY

12.3.1 Inadequate method for the control of radioactive materials which may be inadvertently released in spacecraft modules.

12.4 HUMAN ERROR

12.4.1 Reduced work force competence and ill-considered improvisations that characterize tightly scheduled, multiple shift operations.

12.4.2 Insufficient technical review of planned test procedures, including changes and deviations generated during tests.

12.4.3 Simultaneous tests on the same vehicle controlled by different groups not adequately coordinated.

12.4.4 Inadequate protection of pressure vessels and pressure lines from damage by dropped tools, slipping wrenches, drills, or incorrect sized bolts and screws.

12.4.5 Failure to remove covers or seals from overboard dump ports, pitot and static pressure sensing ports, and pressure relief vents.

12.4.6 Inadequate provisions for exchange of technical information between shifts performing a continuing test.

12.4.7 Insufficient planning and operator training and rehearsal for foreseeable emergencies.

12.4.8 Docking without deactivating incompatible vehicle stabilization systems.

The change in vehicle mass or differences in stabilization system response characteristics in the two vehicles can cause severe oscillations with excessive waste of control system propellants.

12.4.9 Overloading of spacecraft on board computer by failure to remove inputs not being used.

12.4.10 Failure to follow procedures rigorously that require a callout of functions to be performed and an affirmative response that each function has been accomplished.

12.5 IMPROPER PROCEDURES

12.5.1 Unnecessarily early arming of systems.

12.5.2 Mating and demating of electrical connectors without removing voltages from the powered side(s) of the connector, where the connector has not been specifically designed to tolerate this type of operation.

12.5.3 Unrecognized damage to flight hardware resulting from prior use in training exercises.

12.5.4 Failure to verify compatibility of electrical inputs from ground equipment to spacecraft system immediately prior to connecting for tests.

12.5.5 Unnecessary delay in disarming systems no longer needed.

12.5.6 Inadequate provisions for obtaining and verifying equalization of internal and external pressures prior to opening of hatches or pressure systems.

12.5.7 Check valves with soft seats subjected to higher than design pressure differentials during testing.

12.5.8 Spontaneous ignition of "Pastra-Jell" and aluminum wool used in cleaning.

12.5.9 Use of nonconductive plastic coverings over spacecraft or equipment containing pyrotechnic devices.

12.5.10 Using metal tools to troubleshoot powered-up electronic equipment.

12.5.11 Failure to maintain an inert gas blanket over propellants in tanks.

12.5.12 Failure to purge liquid hydrogen systems with gaseous helium prior to introduction of liquid hydrogen.

12.5.13 Failure to relieve pressure completely to an accurately measured level low enough to prevent dangerous motions or sprays when systems are opened.

12.5.14 Use of halogenated hydrocarbon solvents to clean nitrogen tetroxide systems (e.g., Trichorethylene cleaning fluid).

12.5.15 Failure to verify operational readiness of safety systems.

12.5.16 Failure to obtain a final end-to-end check of space vehicle control and stabilization systems in the launch configuration.

12.5.17 Overstressing of flight articles in testing. Failure to verify safety of a planned test on a flight article by prior tests on a prototype.

12.5.18 Failure to require a detailed reverification of circuit and component condition after an inadvertent overvoltage, polarity reversal or connector disconnect.

12.5.19 Overheating of solenoid valves in ground tests (dry).

12.5.20 Uncalibrated pressure relief devices.

12.5.21 Failure to maintain historical records of electrical signature tests on critical solenoid valves.

12.5.22 Propellant loading procedures that permit periods of time when propellant in the spacecraft propellant tanks is under greater pressure than that existing in the spacecraft gas manifold system.

Even though system leak checks are made prior to loading, there is a possibility of propellant leakage into the spacecraft plumbing. When the pressurization system is activated in flight the leaked propellant can freeze and interfere with operation of the pressurization system or can be forced into the opposite propellant tanks, when oxidizer and fuel tanks have a common pressurization system.

12.5.23 Working on live electrical equipment near pressure lines or tanks containing hazardous fluids or high pressures.

A short circuit from hot wires through metal tools to grounded pressure lines or tanks can cause rupture and ignition of fluid sprays.

12.5.24 Entering tanks or confined spaces without protective equipment and procedures.

12.5.25 Excessive or uncontrolled cycling or operation of limited life/cycle flight hardware which could cause inflight failure because of wear-out.

12.5.26 Lack of rigorous housekeeping procedures which prevent accumulation of flammable materials outside stowage containers.

12.5.27 Use of malfunction procedures which place crewmen in an unsafe posture.

12.5.28 Crew timelines which do not provide adequate time to accomplish an operation or series of activities.

12.5.29 Inadequate requirements and procedures for retesting systems after changes.

12.5.30 Failure to provide rapid response postflight safing team, under a single activities manager, consisting of:

(1) Personnel with detailed system knowledge, an understanding of safety requirements, and capable of making sound, on-the-spot, decisions.

(2) Detailed, preplanned procedures for accomplishing both nominal and contingency postflight safing.

(3) A full complement of operational and protective GSE for preforming nominal and contingency safing operations.

12.6 HANDLING OF EQUIPMENT

12.6.1 Inadequate procedures for handling and transferring hazardous fluids or materials in a pressurized area.

12.7 OPERATIONAL STATUS INFORMATION

12.7.1 Failure to provide an equipment operator with an immediate and positive indication of system response to his control actions.

12.7.2 Means not provided to verify the integrity of a docking hatch seal before separating a docked module or vehicle.